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TR-1161  
May 15, 1972

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**SPACE SHUTTLE  
RECOMMENDATIONS BASED ON  
AIRCRAFT MAINTENANCE EXPERIENCE**

(NASA-TM-X-68646) SPACE SHUTTLE  
RECOMMENDATIONS BASED ON AIRCRAFT  
MAINTENANCE EXPERIENCE (NASA) 17 p HC  
\$3.00

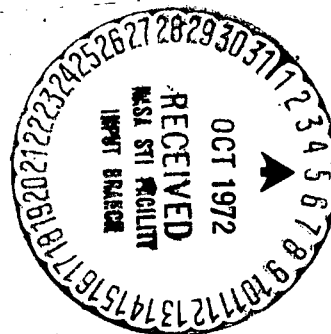
CSCL 22B

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**TECHNICAL REPORT**

**JOHN F. KENNEDY SPACE CENTER, NASA**

**TR-1161**

**SPACE SHUTTLE  
RECOMMENDATIONS BASED ON  
AIRCRAFT MAINTENANCE EXPERIENCE**

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# **SPACE SHUTTLE RECOMMENDATIONS BASED ON AIRCRAFT MAINTENANCE EXPERIENCE**

## **1. INTRODUCTION**

Two representatives of the Kennedy Space Center (KSC) Space Shuttle Task Group visited four Air Force Air Material Areas for the primary purpose of obtaining recommendations pertaining to the development of Space Shuttle design guidelines. These recommendations were based upon Air Force across-the-fleet aircraft maintenance experience.

The design guidelines contained in this report are intended to supplement TR-1105/ "An Analysis of Some Apollo/Saturn V Design Features Applicable to the Space Shuttle Which Resulted in Operational Difficulties." TR-1105 provides design guidelines based upon space vehicle experience while this report primarily provides design guidelines based upon experience with those systems peculiar to aircraft only, i.e.; landing gear and air breathing propulsion. Recommendations are also provided for aircraft structures, hydraulics, and materials and processes.

The contents of this report have not been formally coordinated with the Air Force Logistics Command (AFLC), therefore; none of the design guideline recommendations contained in this report are intended to represent an Air Force position on any issue. The recommendations are proposed primarily for consideration in the early phases of Space Shuttle design as a means of enhancing system maintainability.

## **2. AIRCRAFT SYSTEMS**

Design guidelines and considerations for the landing gear system and air breathing propulsion systems are contained in paragraphs 2.1 and 2.2.

### **2.1 LANDING GEAR SYSTEM**

Considerations should be given to landing gear systems previously developed for existing aircraft such as the B-52.

**2.1.1 MAIN GEAR.** The B-52 main wheel assembly is qualified to 71,000 lbs., the 56 x 16 38 Ply tire is qualified to 76,000 lbs. and currently lasts for approximately 150 landings, the brake is qualified to 16,767,000 ft. lbs. normal stop, 30,181,000 ft. lbs. high energy stop, and 40,600,000 ft. lbs. rejected take off (RTO) one stop.

**2.1.2 ANTI SKID CONTROL.** The B-52 anti skid system should be considered for Space Shuttle use.

a. The anti skid control box should not be located in the gear wheel wells or in any area where damage from tire blowouts, thrown treads, or other similar landing incidents may occur.

b. The anti skid control system should have touchdown protection to prevent locked brakes in the event that the pilot lands with feet on the brake pedals.

**2.1.3 BRAKES.** The brakes should have a positive method of retraction to the OFF position.

**2.1.4 EMERGENCY RELEASE SYSTEM.** Emergency gear extension by a mechanical cable release of the uplatches to allow free fall extension is a desirable feature. A bungee extension assist should be considered for overcoming windloads and to insure a positive downlock following free fall extension.

**2.1.5 TIRES.** Tires and wheels should not be subjected to temperatures over 250°F. A method should be provided to determine maximum temperatures reached in the wheel wells during reentry.

**2.1.6 SIDE LOADS.** A coefficient of friction of 1.0 should be used to establish gear side load. In-service failure of landing gear components have indicated that the 0.8 specified in MIL-A-8862A is not adequate.

**2.1.7 STRUCTURAL COMPONENTS.**

a. All major components should be shot peened on exterior and interior surfaces.

b. Costly fatigue testing can be reduced by adding to the static test program. The recommended approach is to conduct surface strain surveys at or near design limit loads. Stress coat and photo stress techniques can be used to locate critical or questionable points in the structure and strain levels can be established by the use of strain gages applied to the appropriate points. A strain survey of this type can then be used to make needed design modifications prior to production and also to establish fatigue life by applying analytical methods.

c. All joints of landing gear structural links should be designed with flanged bushings.

d. Lubrication fittings should be provided at both dynamic and static joints. Pipe thread fittings are not acceptable. Spiral grooves in bushings, or other suitable means, should be incorporated to provide full lubrication capability under system loads.

e. The use of press fit assemblies should be avoided except for bushing or sleeve retention.

f. All threads on landing gear structural components should be of round bottom configuration.

g. Use of chrome plate on aluminum alloy structural components should be avoided. Hard anodize as specified in MIL-A-8625, Type III can be used to provide hardened wear or bearing surfaces on aluminum parts.

h. All landing gear structural parts and assemblies thereof should be designed as interchangeable units. Matched sets are undesirable from the maintenance and supply viewpoint.

i. All major components of the landing gear should have the part number and serial number permanently marked on a raised pad.

j. Cast iron piston rings inside gear struts have proven unsatisfactory. Recommend consideration of aluminum bronze main landing gear piston bushing with green tweed seals instead.

k. Vac-arc remelt steel is recommended as the principle material for the landing gear system. Aluminum 7075 and 7079 in T6 heat treat condition should not be used.

## **2.2 AIR BREATHING PROPULSION SYSTEM**

a. Items such as inlet cowlings, air/particle separator, and oil cooler that affect engine performance should be included in the engine design contract. The entire engine and the inlet system should be the responsibility of a single design contractor.

b. An engine analyzer should be incorporated to detect impending engine malfunctions and to alert the crew prior to engine failure.

c. Inspection port holes should be provided to accommodate a borescope that will permit viewing of all compressor turbine blades and vanes.

**2.2.1 COMPRESSOR SECTION.** The compressor section should contain the following features:

a. Single spool axial flow compressor design requires fewer main bearings thus greatly reducing bearing alignment problems as well as eliminating interstage bleed and the thru shaft arrangement required on dual spool rotors.

b. Split compressor casing design permits ease of maintenance by allowing a minimum amount of engine disassembly to facilitate compressor maintenance and inspection requirements.

- c. Variable stator vanes can be controlled to obtain maximum compressor efficiency, regardless of RPM setting. In addition this type of vane is more easily replaced.
- d. Compressor stackup having a bolted connection of adjacent disks and spacers is a more stable arrangement than the compressor having a number of tiebolts that tie all disks and spacers into a common stackup. In the bolted configuration, the mating flanges are less critical than in the tiebolt stackup configuration.
- e. Single turbine assembly configuration eliminates the requirement for the inner shaft bearing and the thru shaft.
- f. Where practical, engine plumbing should be enclosed to reduce damage during handling and maintenance. External plumbing should be designed with connections at engine split line so that external components can be removed with plumbing attached.
- g. Accessories on a particular engine should be modulized so that all accessories may be removed by removing the gearbox.
- h. If engine design requires use of exotic materials such as titanium or 718 steel an inspection technique should be developed by the manufacturer.
- i. Engine design should incorporate a 10 micron filter element on the scavenger side of the oil system. The filter should be located such that dirty oil cannot flow into the oil cooler or the fuel oil cooler.
- j. All cold section parts subject to corrosion should be protective coated.
- k. Carbon seals should be used in lieu of Garlock type seals when permissible.
- l. Fire sleeving is not desirable on engine hardware from a corrosion and inspection standpoint.
- m. Dual ignition system should be required.
- n. Ample pressure taps should be provided for troubleshooting.
- o. Military standard bolts and nuts should be used in lieu of trapped/welded nuts, nut plates, gang channels, and the like,
- p. Rod ends/uniballs should be lined with self-lubricating material.
- q. All external items should be readily removed and replaced on an installed engine.

- r. Insure positive oil head pressure on oil wetted areas at all times, including initial rotation for starting.
- s. Engine oil system should be independent of all other oil requirements.
- t. Moisture proof all electrical leads, connections, and components.
- u. All engine cases and ducts should have horizontal split lines for ease of inspection and maintenance.
- v. Provide low and high pressure fuel filters that incorporate bypass and contamination indicating features.
- w. Splines must be oil wetted.
- x. Oil pockets/sumps must be full flowing for self flushing to aid coke elimination.
- y. All coatings, processes, and materials should be readily available to overhaul shops.
- z. Mating parts which will wear with service should be manufactured with different hardnesses. Using the softer material on the cheaper part.
- aa. Designs for special tooling should be minimized.
- ab. Engine casing ports with high wear threads should have throw-away thread adapters.
- ac. Avoid blind assemblies for installation and inspection ease.
- ad. Jackscrews, puller grooves, and pusher surfaces should be incorporated when applicable.
- ae. Dowel pins and offset holes should be standardized to 12 o'clock position.
- af. Avoid left hand threads.
- ag. Parts should not permit two way or different locations of installation.
- ah. All bearings should have anti-rotation devices on the races.
- ai. Use mechanical device for indicating bypass of oil filter.
- aj. Screens and chip detector should be installed in scavenge lines.



ak. All lines subject to excessive vibrations should be flex lines.

al. Chafing guards for lines should be transparent spiral/ribbon design for maintenance and inspection ease.

### **3. AIRCRAFT STRUCTURES**

a. A full scale fatigue test should be considered and as a minimum; the primary structural components should be fatigue tested for the equivalent of the life of the vehicle.

b. Flight recorders should be used to measure "G" loads on primary structure to provide continuing input information for a structural integrity program.

c. Fastener holes should be designed to permit reaming so as to permit use of oversize fasteners during service life.

d. Consideration should be given to permanent installation of ultrasonic transducers with accessible connectors in critically stressed structural areas. In addition, eddy current probes should be considered for permanent installation to detect corrosion of thin panels.

#### **3.1 NON DESTRUCTIVE INSPECTION (NDI)**

a. NDI methods should be developed parallel with structural design to provide access openings for such tasks as placement of gamma ray sources and bore-scopes, penetrant application, or magnetization of parts.

b. NDI techniques should be capable of being performed on installed components without disassembling or removing protective finishes from the component being inspected.

c. Areas that should be among those considered for NDI techniques are as follows:

(1) Fuselage: floor panels, airframe with emphasis on structural splices, extrusions, forgings, castings, wing-to-fuselage attach fittings and associated back up structure, horizontal and vertical fins attach fittings and associated back up structure, window/door frames, fasteners/fastener holes, and composite, bonded, and honeycombed structures.

(2) Wings: wing structure, wing joints, wing tips, attach to fuselage fittings, leading edge assemblies, fasteners/fastener holes, aileron attach fittings and associated back up structure, and composite, bonded, and honeycombed structures.

(3) Vertical Fin: attach to fuselage fittings, internal structure, rudder attach fittings and associated back up structure, fasteners/fastener holes, and composite, bonded, and honeycombed structures.

(4) Components: valves, jackscrews, actuators, tubing, ducts, packs, filters, pumps, accumulators, tanks, converters, wiring runs, black boxes, instruments, circuit boards and electrical panels.

(5) Control Surfaces: flaps, rudders, tabs, ailerons, spoilers, elevators, support brackets, hinges/hinge pins, attach fittings, and counterbalances.

#### **4. HYDRAULIC SYSTEM**

a. Hydraulic lines should be welded or brazed rather than swaged in all inaccessible areas.

b. MIL-H-83283 fluid is recommended because of its fire resistance. This fluid is also compatible with equipment using MIL-H-5606, however; the effects of long term exposure to a vacuum have not been determined.

c. A separate electric motor/hydraulic pump combination for nose gear deployment and steering should be considered as a means of eliminating long hydraulic line runs from the auxilliary power unit (APU) to the nose gear area.

d. Recommend consideration of 15 micron absolute non bypass filters per MIL-F-8815B. Use of differential pressure transducers tied to a central filter maintenance panel to avoid necessity of opening panels for visual inspection is also recommended.

e. The design should consider use of variable displacement pumps in lieu of accumulators. Problems experienced with F-4 accumulators favor this approach, however, reliability of the system has not yet been demonstrated.

f. In many hydraulic systems the valves are assumed to return to a neutral position upon failure of the positioning device. Where this failure mode is assumed the specification should require tests to demonstrate the fail safe position under actual operating condition, including such conditions as allowable internal leakage and reduced spring tension.

g. When periodic sampling of hydraulic fluids is necessary a quick disconnect should be included and located downstream of filter banks.

## 5. MATERIALS AND PROCESSES

a. Boron-aluminum composite parts that are subject to damage should be electrolytically nickle plated and vacuum heat treated after plating to provide a strong bond between the nickle and substrate. This provides an excellent brazing surface if repairs should be required.

b. All highly stressed cyclic loaded parts should be shot peened, particularly machined aluminum alloys with exposed short transverse end grains.

c. Alloy 7075-T73, or 7049-T73 for forging should be used where low stress is acceptable. For high stress corrosion resistant areas 7075-T6 or 7175-T6 should be used.

d. Avoid the use of chrome plate on aluminum alloy structural components. Hard anodize as specified in MIL-A-8625, Type III can be used to provide hardened wear or bearing surfaces where required on aluminum parts.

e. Extensive use of D6AC steel in the F-III aircraft has resulted in unusual corrosion and process problems. D6AC steel starts to rust following mild exposure and protective coatings have to be unusually protective to prevent corrosion.

f. Avoid use of brittle materials such as 7178 aluminum.

g. Avoid use of cadmium in contact with titanium. Cadmium causes embrittlement of the titanium.

h. Polyvinyl Chloride (PVC) plastic materials should be avoided if possible for the following reasons:

(1) PVC has a relatively low heat distortion temperature of 130°F to 190°F. The brittle temperature range is considered poor at 32°F to 40°F.

(2) PVC compounds can easily decompose from exposure to heat and ultraviolet light. Upon deterioration the plasticizer migrates to other PVC surfaces to accelerate the rate of deterioration. Since most plasticizers are excellent solvents, materials contacting a defective PVC compound would be dissolved, this includes paints and some plastic materials in addition to PVC.

(3) Mild heat, in the range of room temperature to 250°F, causes a dehydrochlorination of the PVC compound. In this process, hydrogen chloride gas is liberated to act as a catalyst for further dehydrochlorination (degradation) and can combine with moisture in the air to form hydrochloric acid; a very corrosive media.

## **6. PROGRAM SUPPORT**

### **6.1 DATA HANDLING**

a. A single logistics management should be established for both NASA and DOD programs.

b. The engineering data bank should remain at the contractors facility throughout the DD T&E phase and should be totally computerized or the drawings and specifications indexed and cross referenced for quick access. The data handling system should also provide remote access terminals where needed at NASA, DOD, and contractor facilities.

c. It is recommended that the computer as well as the software, be procured at the time the contract is negotiated. This would allow ultimate turnover of the entire system to the government without reprogramming or restructuring the data.

d. Information should be stored in the data bank to support the following requirements:

- (1) Configuration accounting/management.
- (2) Technical orders to first level maintenance.
- (3) Reliability/maintainability.
- (4) Aging and surveillance.
- (5) Test procedures/reports.
- (6) System analysis.
- (7) Engineering drawings and specifications for maintenance and engineering support.
- (8) Provisioning worklists.
- (9) Nondestruct test/inspection.
- (10) Computer determination and prediction of failures and maintenance actions.

e. Proprietary or non-proprietary stamps should be on all data as applicable. In those instances where the government cannot obtain unlimited rights to the data for a spare part then a performance specification should be acquired.

f. All system specification data in terms of technical comparisons such as voltage and current should be established during the item and system design phase.

g. The manufacturer of each component should be responsible for the accuracy of the component overhaul manual.

## **6.2 AFLC CAPABILITY**

It is recommended that Air Material Area (AMA) repair capabilities be utilized by NASA as well as DOD, where the existing capability is adequate. Development of a Level III maintenance plan will be the subject of a separate report. Following is a preliminary list of types of LRU's that are considered candidates for overhaul and repair at AMA installations.

### **6.2.1 FLIGHT HARDWARE**

#### **a. Air breather engines and system components.**

- (1) Engine assembly**
- (2) Starter**
- (3) Starter isolation valve**
- (4) Booster pumps (fuel)**
- (5) Fuel quantity gage**
- (6) Isolation valves**
- (7) Connector, pneumatic ground start**
- (8) Pneumatic ducts, starter supply**
- (9) Engine vibration pickup**

#### **b. Avionics.**

- (1) Navigation and landing aids such as TACAN and ILS.**
- (2) Voice transceiver compatible with standard air traffic control frequencies.**
- (3) ATC transponder**
- (4) Radar altimeter**

- (5) Flight Recorder
- (6) VHF and UHF antennas
- (7) Inverters
- c. Atmospheric flight instruments such as air speed indicator and artificial horizon.
- d. Hydraulic Systems.
  - (1) Pumps
  - (2) Actuators
  - (3) Valves
  - (4) Accumulators
  - (5) Pressure regulators
  - (6) Indicators
  - (7) Transducers
- e. Landing Gear System.
  - (1) Struts
  - (2) Steering and braking systems
  - (3) Damper
  - (4) Wheel assembly
- f. APU
  - (1) Generators
  - (2) Hydraulic pumps

## **6.2.2 GROUND SUPPORT EQUIPMENT (GSE)**

When GSE requirements can be specified it may be economical to request that certain standard items be initially provided to KSC, as well as Vandenberg, by an AMA. These items, such as start carts, could then be included in regular AMA procurement activities and provided as government furnished equipment (GFE). Items of GSE that should be considered for AMA support are as follows:

- a. Portable ground power supply units.
- b. Radar altimeter test units.
- c. TACAN test units.
- d. Portable ground air conditioning units.
- e. Breathing air servicing carts.
- f. Engine start cart.
- g. ABES oil analyzer unit.
- h. Portable ground hydraulic cart.
- i. Air breathing engine ground test equipment.

## **6.2.3 DEPOT LEVEL INSPECTION AND REPAIR AS NECESSARY (IRAN)**

It is likely that depot level IRAN will be accomplished at KSC and Vandenberg AFB, in this event; the same depot/contractor teams and transportable tooling should be used at each location.

## **6.2.4 AIR MATERIAL AREA REPAIR ACTIVITIES**

Types of items for which each AMA is primarily responsible is as follows:

- a. Sacramento, California (SMAMA)
  - (1) Aircraft and airframe structural components
  - (2) Electrical wire and power distribution equipment
  - (3) Instruments and laboratory equipment
  - (4) Communications Equipment (Ground & Airborne)

**b. Ogden, Utah (OOAMA)**

- (1) Aircraft and airframe structural components**
- (2) Engines, turbines, and components**
- (3) Aircraft components and accessories**
- (4) Maintenance and repair shop equipment**
- (5) Instruments and laboratory equipment**
- (6) Rocket engines**

**c. San Antonio, Texas (SAAMA)**

- (1) Aircraft and airframe structural components**
- (2) Aircraft components and accessories**
- (3) Engines, turbines, and components**
- (4) Engine accessories**
- (5) Pipe tubing hoses and fittings**
- (6) Maintenance and repair shop equipment**
- (7) Medical, dental and vet. equipment**
- (8) Communication equipment (Airborne)**

**d. Oklahoma City, Oklahoma (OCAMA)**

- (1) Aircraft and airframe structural components**
- (2) Engine accessories**
- (3) Guided missiles**
- (4) Communication equipment (Ground)**



**e. Macon, Georgia (WRAMA), Warner Robbins**

- (1) Aircraft and airframe structural components**
- (2) Ships, small craft, pontoons, and floating docks**
- (3) Pumps and compressors**
- (4) Plumbing, heating, and sanitation equipment**
- (5) Clothing and individual equipment**
- (6) Guided missiles**

**f. Newark, Ohio (NAFS)**

- (1) Inertial guidance equipment calibration**
- (2) Meteorology equipment calibration**
- (3) Instrument calibration**